Ultrafiltration Membrane Polishing System for Shipboard Treatment of Oily Wastewater

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ABSTRACT

The U. S. Navy currently uses parallel-plate Oil/Water Separators (OWS) to process oily wastewater aboard ship. OWS effluent does not consistently meet current discharge restrictions and may not meet increasingly stringent local, national and international environmental requirements. Under the sponsorship of the Chief of Naval Operations, and by direction of the Naval Sea Systems Command, Naval Surface Warfare Center, Carderock Division is developing a family of secondary treatment systems using ultrafiltration membranes to polish the effluent from the OWS. These systems will reduce the concentration of oil in bilgewater discharges to less than 15 ppm; the goal for system effluent is to contain less than 5 ppm. Thousands of hours of laboratory and shipboard tests of membranes and membrane systems have shown the feasibility of membrane filtration in treating oily wastewater. Based on these tests, a 10 gal/min prototype system was designed, fabricated, and installed on USS CARNEY (DDG 64). This system has effectively processed shipboard oily wastewater for over 1 year, creating an overboard discharge containing an average of less than 5 ppm oil. Evaluation of this system continues to determine membrane replacement frequency and system operational and maintenance requirements. A more rugged ultrafiltration system is being developed for operation on a higher bilgewater producing ship next calendar year. Completion of research and development of the ultrafiltration system will lead to procurement and installation for new construction ships.

INTRODUCTION

One of the U.S. Navy's primary environmental concerns is overboard discharge of liquid waste from ships of the fleet. A major source of overboard discharge is oily wastewater (bilgewater), which collects in most machinery spaces and is generated in volumes too large for long-term storage. Bilgewater is a highly variable mixture of potable water and seawater with contaminants from a number of sources. Typical contaminants may include fuels, oils, and hydraulic fluids, detergents and Aqueous Film Forming Foam (AFFF), incidental leaks from blackwater/graywater systems, and a wide variety of other substances, potentially including corrosion products, paints, and solvents.

The type and amount of bilgewater contaminants vary widely based on a ship's operations, equipment performance, casualties, repairs, and other events. The generation rate of bilgewater ranges from over 50,000 gallons per day on many older aircraft carriers to less than 1,000 gallons per day on newer “dry bilge” combatants such as the *Arleigh Burke* Class. Larger, older ships frequently produce large volumes of dilute waste, while newer, smaller ships generally produce smaller volumes of more concentrated waste.

CURRENT REGULATIONS/EQUIPMENT

The overboard discharge of oil from U.S. Navy ships is currently governed by OPNAVINST 5090.1B, which implements Defense Department Directive 6050.15, "Prevention of Oil Pollution From Ships Owned or Operated by the Department of Defense." This directive is based on Public Law 96-478, "The Act To Prevent Pollution from Ships." These regulations limit discharges of oil to less than 20 ppm in port and 100 ppm at sea. To meet these thresholds, the U.S. Navy uses oil/water separators (OWS) such as the 10 gal/min model OPB-10NP aboard ships. The 10NP is a parallel-plate OWS which uses gravity separation and coalescence to remove free oil from oily wastewater (see Figure 1). The pressure-feed 10 gal/min 10NP OWS has supplanted the earlier 10N OWS, which uses a suction pump on the discharge side of the OWS and is still installed on several U.S. Navy ships.

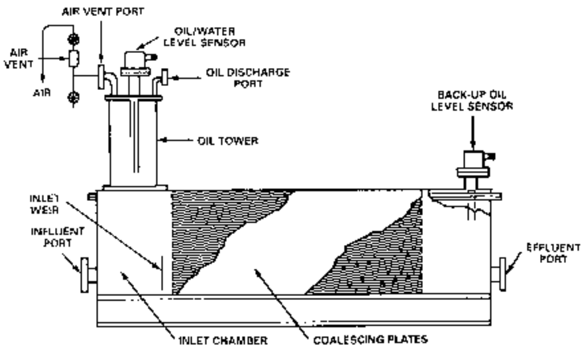


Figure 1. U.S. Navy OPB-10NP OWS.

ANTICIPATED REGULATIONS/PROBLEM DEFINITION

Shipboard parallel-plate separator performance has not reliably met existing effluent quality regulations. The use of detergents in machinery space cleaning can cause stable oil/water emulsions which cannot be treated effectively by the OWS. This problem is exacerbated in newer "dry bilge" ships. Furthermore, the Navy is anticipating more stringent discharge requirements from the Uniform National Discharge Standards Act (UNDS), the Clean Water Act, and local, national, and international regulations. In addition, increasing international restrictions could impose operational limits on U.S. Navy ships in the territorial waters off foreign countries. The operations of U.S. Navy ships cannot be encumbered by these constraints.

OBJECTIVE

Under sponsorship of the Chief of Naval Operations and by direction of the Naval Sea Systems Command, Research and Development Programs Division, (SEA 03R16) the Carderock Division of the Naval Surface Warfare Center (CDNSWC) is developing a family of secondary treatment systems using ultrafiltration membranes to polish the effluent from the OWS. These systems will reduce the concentration of oil in bilgewater discharges to less than 15 ppm; the goal for system effluent is to contain less than 5 ppm of oil. The existing OWS has proven to be highly effective at removing bulk oil from oily wastewater; the polishing system is intended to remove the emulsified oil which OWS cannot remove.

APPROACH

An extensive Research, Development, Test, and Evaluation (RDT&E) project was launched to develop a system for use on Navy ships. System goals are high reliability, low manpower requirements, low lifecycle costs, the use of no consumables such as chemicals in system operation, and, due to the space limitations on Navy vessels, small system size and weight. Furthermore, Navy efforts have focused on developing a system which provides a "fail-safe" barrier to overboard discharges of oil.

An incremental approach to ultrafiltration system development has been conducted to ensure successful system operation throughout the Fleet. Baseline testing of membranes in the laboratory and in the field has been conducted, followed by the design, fabrication, and testing of small-scale systems in the laboratory and aboard ship, and the design, fabrication and testing of full-scale systems in the laboratory and aboard ship.

SYSTEM DEVELOPMENT

Membrane Technology

A survey of technologies potentially capable of meeting Navy needs in polishing OWS effluent was performed in 1994. Membrane cross-flow filtration was selected as the most promising for shipboard use.

Membranes are asymmetric surface filters with extremely small pore sizes. A thin membrane layer, which may have a thickness as small as 1 µm, is bonded (or formed) onto a more porous substrate. With appropriate membrane selection and implementation, contaminants such as emulsified oil droplets are too large to pass through the separation layer and are rejected at the membrane surface. Clean water (permeate) passes through the separation layer — experiencing significant pressure drop due to the fine pore structure — then passes easily through the large pores of the substrate. Because the separation layer is very thin, high permeate flow rates may be attained with low trans-membrane pressures ranging from 10 to 100 psi.

A layer of rejected oils and other substances is prevented from building up on the surface by imposing a cross-flow of liquid parallel to the surface. This cross-flow sweeps the surface clean and allows long-term operation of a membrane without chemical cleaning. This internal cross-flow stream — known as retentate — contains the oil and other contaminants removed from the feed stream. Retentate is removed and stored for later disposal.

All membranes eventually exhibit symptoms of fouling — a gradual blockage of permeation — and must be cleaned or replaced. The fouling rate is a function of a number of process variables, especially membrane type, cross-flow velocity, temperature, permeate flow rate, and the character of the feed and retentate streams. Successful application of membrane technology demands careful consideration of these design parameters.

Initial Field Testing

A prototype system was designed and installed by CDNSWC at Naval Weapons Station, Earle to evaluate the ability of ultrafiltration membranes to process shipboard-produced oily wastewater. This shore-based system processed bilgewater taken from U.S. Navy ships at 10 gal/min. The system incorporated polymeric polysulfone hollow-fiber membranes polishing 10NP OWS effluent. Over 200,000 gallons of oily wastewater were processed by the system. Chemical analysis of the permeate proved that membranes were capable of meeting discharge standards; an average membrane effluent actual oil concentration as measured by the CDNSWC method of oil-in-water analysis (a variant of EPA Method 418.1) of less than 5 ppm was produced.

While demonstrating that membrane filtration could effectively treat ship-produced oily wastewater, the Earle system was relatively large and required frequent chemical cleaning to maintain performance. In addition, the system proved vulnerable to chemical attack; the system processed oily wastewater contaminated by a paint thinner spill which caused membrane failure.

Failure of the polymeric membranes upon exposure to solvents highlighted an important Navy concern; namely, that systems preventing violation of discharge regulations be highly reliable and capable of handling virtually any contaminants which might possibly enter bilgewater.

Membrane Screening Tests

A number of membranes are commercially available worldwide, some highly chemically resistant and others offering cost, size and weight or reliability advantages. To meet the Navy's needs, membrane technologies must offer a combination of these attributes and produce a system appropriate for installation on ship. Table 1 lists commonly available membrane types and their primary advantages and disadvantages in this application.

Membrane performance is strongly dependent upon the feed stream being processed. CDNSWC initiated a testing program to evaluate different membranes against a standard OWS effluent simulant containing 100 ppm of an oil mix and 25 ppm of a cleaning chemicals mix (Table 2). Over twenty membrane types were evaluated in the laboratory for long-term performance and permeate quality. Figure 2 presents relative cost per gallon for 15 different membranes tested simultaneously. Relative costs are given because absolute cost is a function of both initial capital outlay and the potential of a given membrane to be cleaned and re-used. The target membrane replacement cost is \$0.02 - \$0.04 per gallon processed.

Each membrane type offers advantages, however, ceramic membranes were judged more chemically resilient than others. As shown in Figure 2, the 50Å dense-pack silica ceramic membranes yielded low cost and consistently produced permeate containing less than 5 ppm oil; most larger pore size membranes could not achieve this. These membranes also resulted in a system design containing less space and weight than competing ceramic membranes. The dense-pack membrane is shown in Figure 3.

Long-Term Testing

Based on the low cost, high permeate quality, and chemical inertness of dense-pack ceramic membranes, laboratory testing was initiated to simulate long-term shipboard use. Testing was conducted with several different membrane formulations and pore sizes and under various operating conditions. Tests evaluated the long-term permeate quality, fouling rate, and physical stability of these membranes, and aided in selection of process parameters for full-scale development.

Figure 4 illustrates the testing history of two small-scale dense-pack silica ceramic membranes with 50 Å separation layers. These membranes processed oily waste containing 1000 ppm oil mix and 250 ppm cleaning chemicals for 1000 hours. A cross-flow velocity of 4 m/s was maintained throughout testing, as was a trans-membrane pressure of 275.6 kPa (40 psi). One membrane was left to soak in clean water each night; the other was left in retentate.

These membranes effectively rejected oil, averaging 2.2 and 2.0 ppm permeate oil concentrations. The membrane soaked daily in clean water exhibited substantially slower fouling and consequent longer life. Importantly, a rapid drop in flux was observed during the first 100 hours of operation. The high fouling rate is a result of overfluxing the membranes. Fouling was not proportional to gallons processed at high flow rates.

Flux Rate Testing

A series of tests was performed to determine the relationship between the permeate flux rate and the associated fouling rate. The tests were conducted in a similar manner to that described above, except that valves were used to throttle the permeate flow rate to constant values. Results given in Table 4 indicate

Table 1. Major commercially available membrane types.

Type	Description	Advantages	Disadvantages
Hollow fiber polymeric	Bundled membrane fibers with internal diameter ~ 1 mm	Low cost Physically robust Lightweight	Random fiber breakage Subject to chemical and biological attack
Tubular polymeric	Individual tubes with internal diameter ~ 1 cm	Not subject to clogging	Low packing density Subject to chemical and biological attack
Spiral wound polymeric	Rolled flat membrane sheets with a spacers	Low cost Lightweight	Subject to physical damage with improper operation, chemical and biological attack
Tubular ceramic	Sintered ceramic elements with cylindrical tubes	Chemically inert	Expensive, Low packing density Subject to breakage from mishandling
Dense-Pack Ceramic	Sintered ceramic elements with square tubes	Chemically inert Low cost High membrane area density	Subject to breakage from mishandling

Table 2. Oil and cleaning chemical mixtures used in CDNSWC testing.

Oil Mixture (CDNSWC Mix #4)	Cleaning Chemical Mixture
50% diesel fuel marine (MIL-F-16884H) 25% 2190 TEP steam turbine lube oil (MIL-L-17331H) 25% 9250 diesel lubricating oil (MIL-L-9000H)	50% general purpose nonionic detergent (MIL-D-16791G) 25% cleaning solvent (Stoddard Solvent) 25% commercial detergent (Liquid Tide)

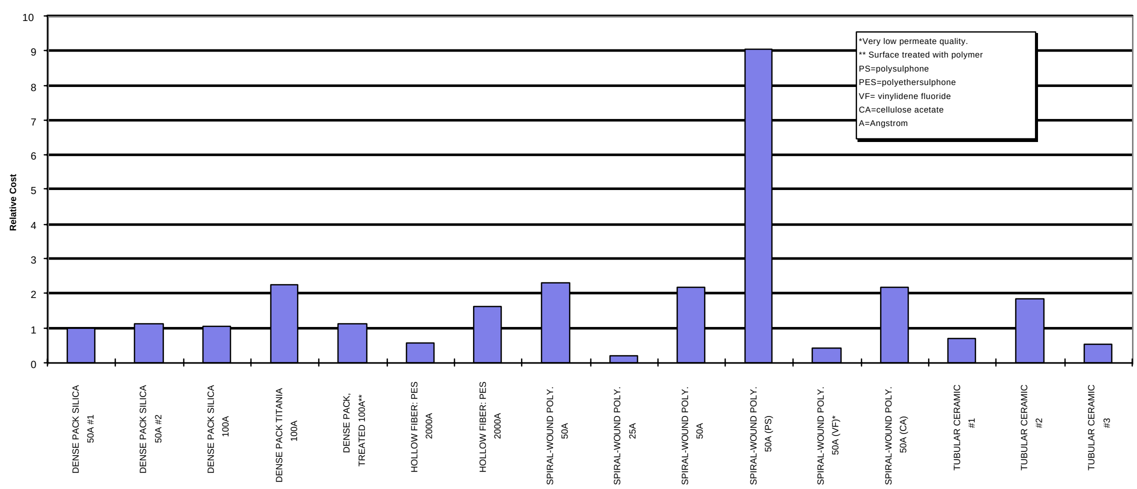


Figure 2. Relative costs of 15 different membranes evaluated under identical conditions while processing 100 ppm oil mix and 25 ppm cleaning chemicals mix.

(Identical conditions means equal pump power per square foot of membrane area and equal permeate flux. Note that no spiral wound membrane could be operated with sufficient cross-flow velocity because of membrane fragility.)

(between cleanings) of greater than 3,550 hours were achieved.

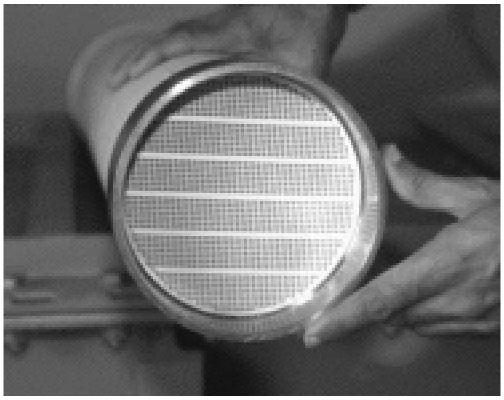


Figure 3. Dense-pack ceramic membrane; full scale module with 11.2 m^2 surface area (120 ft^2).

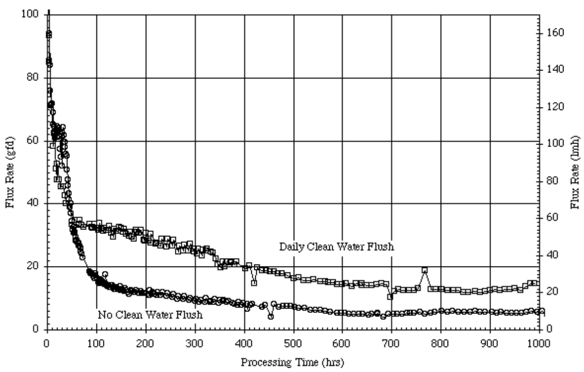


Figure 4. Results of 1000 hour test of silica ceramic dense-pack membranes: flux vs. hours.

Table 4. Effect of permeate flux rate on membrane fouling.

Flux (gfd)	Flux (lmh)	Resistance allowed (psi/gfd)	Estimated Lifetime (hr)	Lifetime Total (gal/ft^2)
30^{+}	51	2	3,550	4,440
45	76	1.33	>>2,500	>>4,700
60	102	1	3,800*	9,500*
75	127	0.8	1,350	4,100
90	153	0.67	200	780

* Projected.
$^{+}$ Results from separate test stand.

that maximum membrane life is achieved at permeate flow rates below 102 liters/m^2·hour (lmh) (60 gallons/ft^2·day (gfd)). Excellent permeate quality was achieved (average = 2.3 ppm) and membrane lifetimes

Contaminants Testing

While ceramic membranes are chemically resilient, it is important that membranes remain impervious to oil during and after contaminant exposure and that membranes not foul excessively if so exposed. A series of tests were performed to evaluate membrane ability to withstand exposure to 11 contaminant groups representative of different types of potential bilgewater contaminants (Table 5). A separate test was conducted for each chemical group listed; membranes processed a mixture of 250 ppm oil, 62.5 ppm cleaning chemicals, and 5000 ppm of each contaminant.

Averaged across all tests without contaminants, the oil concentration in the membrane permeate was 2.2 ppm. The permeate quality was not significantly different after the membranes had processed any chemical group, demonstrating that the membranes were not damaged by chemical action. The ability of membranes to be oil-wetted was also determined as oil breakthrough was detected after soaking a membrane overnight in 4.5% oil, which demonstrated that membranes should be rinsed with clean water prior to shut-down.

Figures 6 & 7 illustrate permeate flux achieved with a cross-flow velocity of 4 m/s (13.1 ft/sec), trans-membrane pressure of 275.6 kPa (40 psi), temperature of 20 C, after concentrating the initial feed by a factor of 4.5×. Flux with contaminant present is shown in Figure 6; Figure 7 shows flux of the same membranes after rinsing with water and processing oil and cleaning chemicals alone.

Permeate flux rate was affected during and after processing many of the potential contaminant chemicals. Many contaminants, such as paints and primers and AFFF, had little effect on membrane performance. Detergents and hydrogen ion concentration (pH) levels above 9 reduced permeate flux while present, but fully recovered when removed. Solvents and pH levels below 3 yielded more lasting fouling, however, relatively high permeate flux rates were recorded even after exposure to extremely high levels of these substances, and good recovery was achieved with water flushing.

Under upset conditions it is possible that membranes will be exposed to bulk oil or that the intended concentration factor will be exceeded as a result of equipment failure. In either of these cases, oil builds up within the membrane system until the membranes foul completely. Tests were conducted to

Table 5. Potential bilge contaminants tested.

Acidic Mixture (pH=1.9)	Citrus Drink Mix, Naval jelly rust remover
Basic Mixture (pH=9.4)	Ammonia, Di/Tri Sodium Phosphate
Saline	Synthetic Seawater
Detergent	"409", "Lysol" Antibacterial Cleaner, "Lysol" Hard Water Stain Cleaner, "Simple Green", Soap Scum Remover
Foam	AFFF
Petroleum Hydrocarbons	Kerosene , Mineral spirits, Synthetic Lube, Used motor oil
Oxidizers	Bleach
Paints	Enamel spray paint, Oil-Based Paint, Paint Primer, Zinc Chromate Primer
Solvent (insoluble)	Paint Thinner, Methyl Chloride
Solvent (soluble)	Di/Ethylene Glycol, Isopropyl Alcohol
Treatment Preps	Amerol, Scale Cleaner

Figure 6. Flux while processing contaminant + oil and detergents.

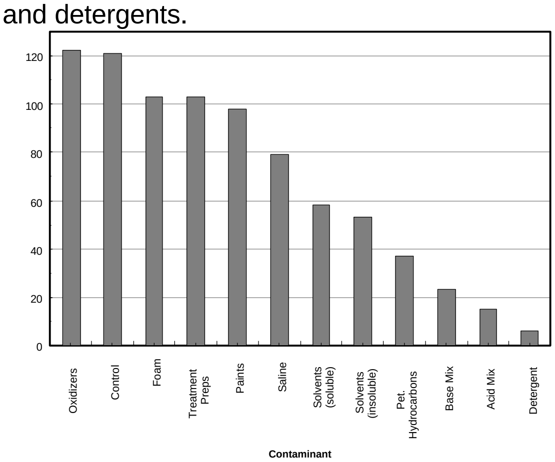
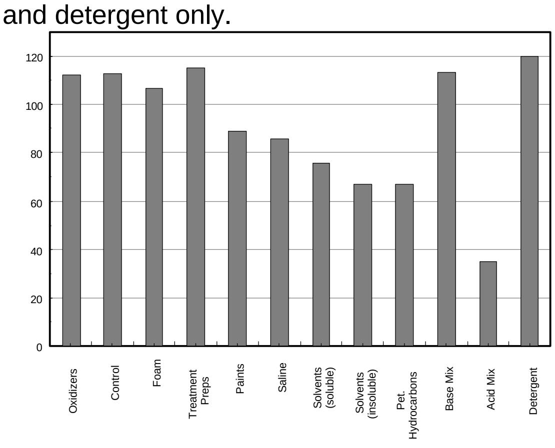


Figure 7. Flux after processing contaminant: oil and detergent only.



ensure that oil would not be discharged overboard in such situations. Membranes continued to process oily wastewater when exposed to bulk oil; almost no effect was observed before sudden flux cessation with 96% oil in the retentate. Membranes also continued to process oily wastewater with a simulated bleed valve failure up to a retentate oil concentration of 54%. In each case, clean permeate containing less than 5 ppm oil was produced.

Volume Reduction Factor Testing

Membranes are a volume-reduction technology, and are consequently of most use if the concentrated waste produced can be incinerated or stored for at least the duration of a mission. A trade-off is necessary between the targeted volume reduction and the membrane life, since increased volume reduction tends to increase fouling rate and thus decrease membrane life.

A series of tests were performed using small-scale ultrafiltration systems in the laboratory. Drawing from the same feed tank, three systems processed an oil/detergent mix at volume reduction factors of 10:1, 25:1 and 100:1. Longest membrane life was achieved by the system processing at 25:1. Permeate quality was relatively constant between the tests, averaging 4.2 ppm oil.

Other tests performed by CDNSWC have shown that membranes are capable of reducing shipboard oily waste by as much as 600:1. Because high concentration factors reduce disposal costs, and because performance differences between operation at 25:1 and 100:1 were moderate, a 100:1 volume reduction was selected for ultrafiltration system operation.

SMALL-SCALE SYSTEM DEVELOPMENT

Based on the extensive design and testing process discussed above, a full-scale shipboard ultrafiltration system was designed. From this, several small-scale systems were designed and fabricated for laboratory and shipboard testing. These systems used the same small scale dense-pack ceramic membranes to simulate full-scale design conditions.

Single- and Two-Stage Small-Scale Systems

Two systems were designed and fabricated to evaluate the effect of staged filtration. The first of these systems incorporated a single-stage process incorporating a feed pump, a recirculation pump, membranes and valving. A second system incorporated a more advanced two-stage filtration

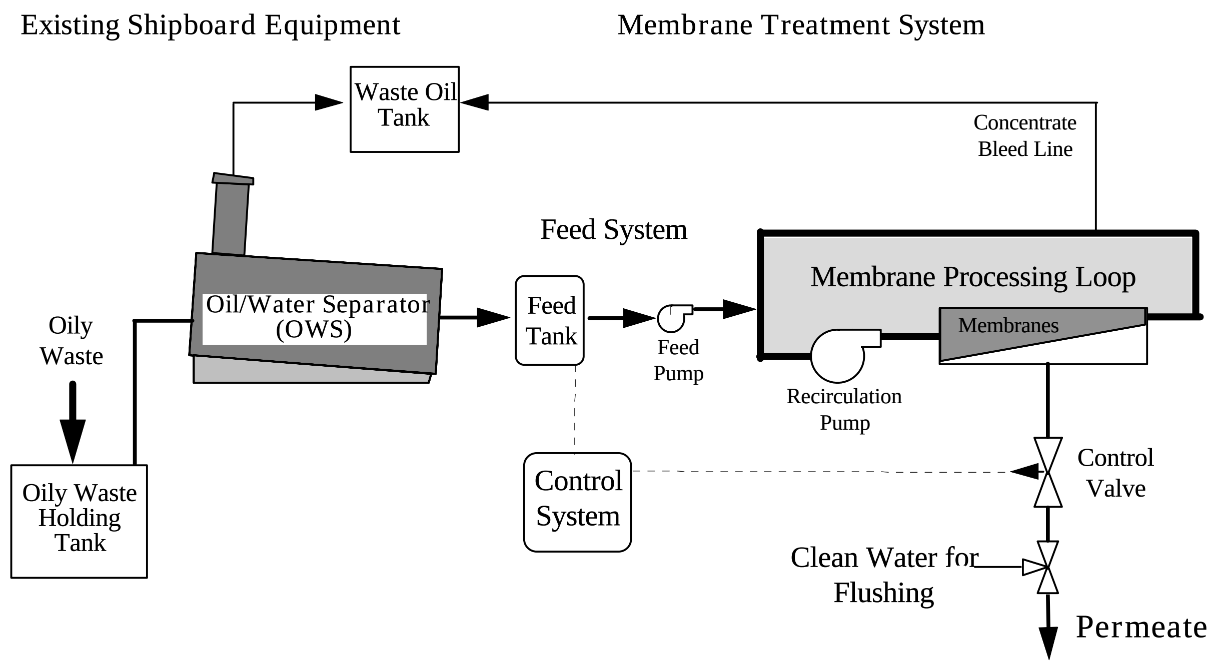


Figure 8. Schematic of full-scale ultrafiltration system design.

design involving an additional recirculation pump and piping. Initial tests were conducted in the laboratory. Average permeate quality was 3.7 ppm during 130 hours of testing the single-stage unit, and 7.9 ppm during 400 hours of testing the two-stage unit.

These systems were installed on USS L Y SPEAR (AS 36) downstream of the ship's 10 gal/min OPB-10N oil/water separator. The systems successfully processed separator effluent for 437 hours at a constant flux of 88 lmh (48 gfd), and concentrated ship's waste by a factor of 100×. Permeate produced by the systems contained 1.1 ppm oil. The membranes also proved capable of removing a large fraction of certain other contaminants from separator effluent, substantially reducing overboard discharge of metals such as copper, zinc, and nickel, and Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS).

Parametric Test Units

Several major full-scale system design parameters were addressed by designing, fabricating, and installing four small-scale systems on USS L Y SPEAR. These systems operated simultaneously and provided design data regarding the effect of membrane cross-flow velocity, backflushing (using potable water or permeate), and the relative effectiveness of single- and two-stage arrangements. These systems operated for a total of over 6000 hours on SPEAR and yielded a wealth of data allowing selection of design parameters for the prototype full-scale system.

PROTOTYPE SYSTEM

Using design parameters developed during small-scale tests, a prototype full-scale ultrafiltration system was designed, fabricated, and installed in the laboratory to accumulate reliability and maintainability data. The ultrafiltration system completed a test simulating the treatment of 180,000 gallons of oily waste for 1 year (300 hours) on a destroyer such as the DDG 51. The system successfully passed the test, producing effluent containing an average of less than 5 ppm oil and less than 15 ppm oil greater than 95% of the time.

A full-scale prototype system was installed on USS CARNEY (DDG 64). The membrane system was configured to process the entire flow rate from the ship's OPB-10NP oil/water separator. The system was upgraded to more rugged materials after 9 months on CARNEY (Figure 9). After 15 months a third refit was performed that updated the system to characteristics listed in Table 6. A diagram of the system operation is presented in Figure 10.

Developed under a "dry bilge" concept, USS CARNEY produces less than 1000 gallons per day of bilgewater, allowing only 1 hour per day of operation for the ultrafiltration system. The effluent from the separator was, however, substantially more contaminated with oil than USS L Y SPEAR

Table 6. Prototype ultrafiltration system characteristics.

Total Weight	2600 lbs wet 2100 lbs dry
System Envelope	108 cubic feet
Total Footprint	18 square feet
Power Required	12 kW (30 Amps) 440 VAC/3 phase

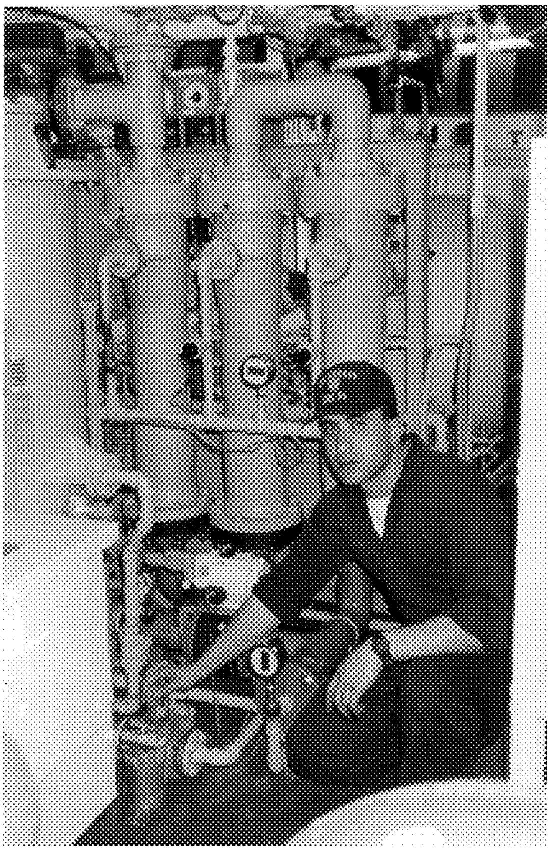


Figure 9. Photograph of full-scale ultrafiltration system on USS CARNEY (DDG 64).

separator effluent.

As of July 1997, the system had processed 70,000 gallons of oily waste during 15 months of operation. 221 hours of system operation were recorded in that time. The 10NP oil/water separator reduced the concentration of oil in bilgewater by 98% from 11,000 ppm to 232 ppm. The ultrafiltration system reduced the concentration of oil in oil/water separator effluent by a further 98% from 232 ppm to 4.7 ppm. The ultrafiltration system remains on CARNEY and will be operated by ship's force during CARNEY's 6-month deployment beginning October 1997 to determine membrane replacement frequency and system operational and maintenance requirements.

Based on the successful demonstration of the ultrafiltration system on CARNEY, the Navy has developed a performance specification for the procurement of ultrafiltration systems for DDG 89 and follow. The Navy will also be installing an ultrafiltration system on USS MCFAUL (DDG 74).

FURTHER DEVELOPMENT

Regeneration Tests

While the ultrafiltration system is being designed to require no shipboard chemical cleaning, methods to regenerate and reuse membranes after shipboard use are being developed. Ceramic membranes are highly chemical and abrasion resistant and thus aggressive cleaning is possible to remove foulants and recover membrane flux. Development of a highly effective regeneration/ cleaning technique could result in greatly reduced life-cycle costs.

Initial tests were conducted using small-scale membranes fouled in testing on USS L Y SPEAR (AS 36). The membranes were removed from the shipboard system, returned to the laboratory, and the foulants were identified using scanning electron microscopy, atomic force microscopy, energy-dispersive x-ray analysis, x-ray photoelectron spectroscopy, and Fourier Transform Infrared (FTIR) spectroscopy. With foulants identified, low-intensity and aggressive cleaning techniques with commercial cleaning chemicals were selected and evaluated. Regeneration/cleaning effectiveness proved highly variable. Nearly 100% recovery was achieved with a membrane subjected to cleaning with clean water and then with bleach (NaOCl). Other membranes cleaned with only clean water or bleach did not recover as well. The low-intensity cleaning techniques tested were successful at removing the bulk of foulants. Better recovery was achieved when membranes were cleaned for longer durations, but membrane recovery generally approached a limiting value. Table 7 summarizes results.

More aggressive cleaning with acids combined with commercial membrane cleaners (basic solutions containing surfactants) has yielded mixed results. While ceramic membranes are chemically resilient, very high and low pH conditions can damage the membrane's filtering efficiency. An average flux recovery of over 83% was achieved for 5 membranes cleaned by strong acids and bases. In 2 cases, however, cleaning was too aggressive, as the membrane filtering efficiency was unacceptably diminished. Development of optimized regeneration techniques continues. Full-scale membranes fouled in testing on USS CARNEY (DDG 64) will undergo analysis for foulant identification and based on these analyses, improved methods to regenerate membranes will be developed and tested. From this testing, the most promising regeneration procedure will be performed on other fouled membranes from CARNEY Regenerated membranes will be returned to shipboard use to determine the long-term effects of regeneration on filtering efficiency and membrane life through a number of regenerations.

Table 7. Effect of membrane cleaning on flux recovery.

Cleaning Technique	Average Flux Recovery
Clean water rinse	40%
100 ppm bleach (NaOCl)	56%
1% Non-ionic detergent	3%

Housing Development

Improved membrane housings are being developed by CDNSWC to reduce ultrafiltration system size, weight, and initial cost. The membranes used by the ultrafiltration system are currently commercially available only in stainless steel housings with 7-inch diffuser sections at each end to ensure that the entire membrane achieves equal cross-flow velocity. Tests at CDNSWC have demonstrated that membranes must be positioned vertically for optimum oil filtering efficiency under shipboard operational scenarios. The 14 inches of system height added by the diffusers resulted in a total height inappropriate for several Navy ship classes. In addition, the metallic housings are subject to corrosion in salt water and may generate corrosion-erosion products harmful to membranes.

CDNSWC performed a Computational Fluid Dynamics (CFD) analysis of the membrane system to evaluate the effects of the diffusers in a shipboard system. Elimination of the diffusers resulted in only slight variations in cross-flow velocity throughout the membrane, and reduced membrane housing length by 32%. Thus CDNSWC began the development of a non-metallic housing for the dense-pack ceramic membranes without use of diffusers. A prototype Glass-Reinforced Plastic (GRP) housing was successfully developed and tested in the laboratory and aboard USS CARNEY (DDG 64). A lighter, less expensive GRP housing is under development.

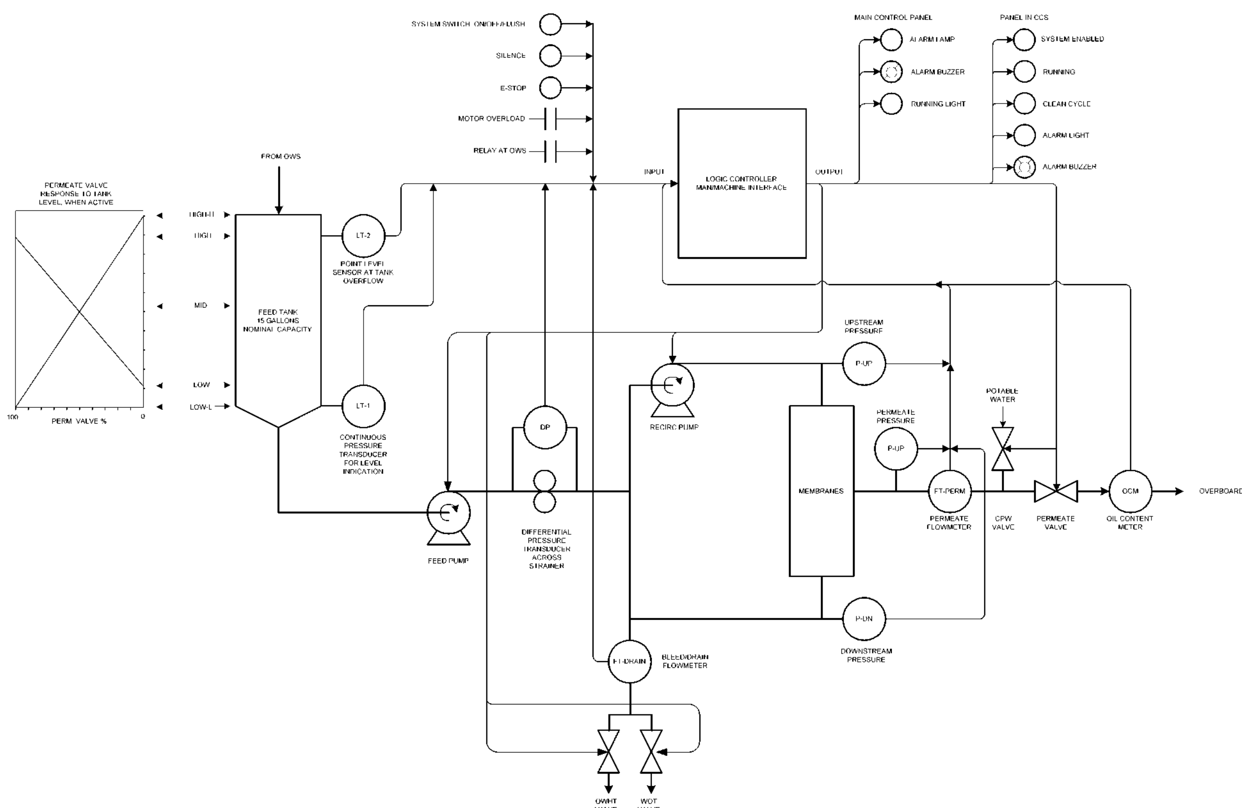


Figure 10. Schematic of new ultrafiltration system under development.

NEW ULTRAFILTRATION SYSTEM DEVELOPMENT

A more rugged ultrafiltration membrane system is being developed for operation on a higher bilgewater producing ship next calendar year. The new system will reflect lessons learned on USS CARNEY, along with improvements gleaned from a Shock and Modal Analysis and a Failure Modes, Effects and Criticality Analysis (FMECA) of the ultrafiltration system. The system schematic is shown in Figure 10, system goals are shown in Table 8.

Table 8. New ultrafiltration system goals.

Total Weight	2500 lbs wet
	2000 lbs dry
System Envelope	75 cubic feet
Total Footprint	15 square feet
Power Required	12 kW (30 Amps)
	440 VAC/3 phase

CONCLUSIONS

The Navy has successfully developed a system capable of meeting oily wastewater discharge regulations. This system uses ceramic ultrafiltration membranes and produces 99 gallons of clean effluent acceptable for overboard discharge for every one hundred gallons of OWS effluent processed. Permeate quality averaging less than 5 ppm — and below 15 ppm 95% of the time — has been achieved aboard ship. Ongoing efforts are focused on reducing the life-cycle cost of the system, improving system operational reliability and maintainability and reducing overall system size. Regeneration studies are underway to reduce costs by allowing membrane re-use. Completion of research and development of the membrane system will lead to procurement and installation for new construction ships.

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